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Providing Intuitive Museum Guidance through Asset-Tracking and Mobile Applications

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Providing Intuitive Museum Guidance through Asset-Tracking and Mobile Applications

by

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Thesis

Presented to the Faculty of the Graduate School

of the University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

December 2010

Dedication

This work is dedicated to my wonderful husband
James Goertz
who has supported and encouraged me throughout the entire process.

Dziękuję Kubusiu!

Providing Intuitive Museum Guidance through Asset-Tracking and Mobile Applications

by

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The University of Texas at Austin, 2010

SUPERVISOR: Christine Julien

The tracking of artifacts in museums can be a cumbersome and error-prone process. A system that performs this tracking manually would help prevent mistakes and could be utilized to help attract and retain museum visitors. This thesis outlines the design and implementation of a three-part system for accomplishing this goal. By combining a powerful RFID infrastructure with a server and an intuitive mobile-device application, the project in this thesis aims to provide an automated way to keep track of artifacts, as well as to provide an application that makes the traversal of the museum intuitive and enjoyable for visitors. The application is built on Apple's iOS platform in order to reach the multitude of users already in possession of iPhones, iPads, and iPod Touches. An initial evaluation shows the system behaves as expected and that it could be a useful tool to museums.

Table of Contents

1.0 Introduction

A trip through a museum should be an informative, enjoyable experience. The lack of direction through exhibits and the confusing nature of museum materials can quickly sour the excursion and make it frustrating, however. Likewise, a staff member who has to manually keep track of all of a museum's artifacts may find the task difficult or cumbersome. Both of these problems could be solved with automated asset tracking paired with an intuitive mobile application.

Artifacts inside museums, even very specific museums whose exhibits seem like they would be unchanging, frequently move throughout the museum. Different artifacts get assigned to different exhibits, the flow of the original exhibit needs to change, or the artifact needs to be put into or taken out of storage [3] [19]. The manual tracking of all these artifacts would not only become cumbersome, but the process could be mistake-prone. If a staff member were to forget to update one artifact in the system, that artifact could be very difficult, if not impossible, to find in the future (These mistakes do not even account for malicious intent, with which a staff member or visitor could attempt stealing an artifact. [10]). Even should all of the artifacts' locations be correctly updated in a museum system, staff members would be in charge of making sure that all museum materials are correctly updated to reflect changes in location or inaccessibility of an artifact. This manual updating of museum materials could also lead to mistakes and costly reprints or redistributions. Finally, a museum visitor is likely interested in learning background information about an artifact. If such information is too expensive to print in a comprehensive booklet, or if the informational placards for artifacts are missing or blocked, the visitor will leave the museum unsatisfied with his or her excursion and may not return in the future. A system that automatically keeps track of all the artifacts in a museum, along with the important information about them, and makes the location and description of these artifacts readily available to visitors in real time could solve many of the problems that plague the analog world of museum navigation and maintenance. Additionally, a pleasant, easy-to-use application that appeals to visitors could ensure their return to the museum and their recommendation of the museum to others.

1.1 Asset-Tracking

Automatic systems that keep track of artifacts or assets are not a new concept. As computing has become more prevalent and more powerful, people have become increasingly interested in harnessing that power for the purpose of automating many things, including asset tracking. This study of keeping track of objects is not limited to the educational, research world, either; asset-tracking technologies are both readily available for purchase [17] and already being used in commercial situations [23].

As might be surmised, the popularity of asset-tracking has led to a variety of different tracking options. Each option has its strengths and weaknesses and applies best to particular situations. One of the most popular and well-known asset-tracking systems is the Global Positioning System (GPS). This satellite-based system produces absolute coordinates for any object that has a GPS communicator onboard [8]. GPS provides surprisingly accurate positions as well, especially considering that the system operates on a global scale. The integration of GPS with other systems would be fairly straightforward, since it is such a prevalent technology. The biggest drawback of GPS, however, is its signals' inability to penetrate through walls and buildings, therefore making it almost unusable in an indoor setting such as a museum.

A second method of asset-tracking is through image recognition. Some systems take advantage of the widespread digital cameras that consumers own, either as standalone units or in mobile phones, and utilize them to recognize objects or locations through image processing techniques [4] [25]. The advantage of this method is the ready availability of digital cameras, as well as a proliferation of digital images. The easy access to this technology and these files makes capturing and interpreting images a feasible process. The disadvantage lies in the unknown variables in image processing. For example, artifacts can be looked at from different angles, and certain perspectives may or may not match up with the images available for processing. Furthermore, while image recognition may identify a particular artifact, other reliable clues have to be in place to know exactly where that artifact is. Implementing image-based tracking could be difficult to do in a museum setting where artifacts move around to different locations, and thus have different backgrounds, and where lighting conditions might change between exhibits. Image-tracking can be effectively used when the pertinent objects are entirely stationary, and therefore will not be placed in front of a different background, or when an extensive collection of pictures of these objects already exists.

Finally, asset-tracking can be implemented using Radio-Frequency Identification (RFID) technology. The basic scheme of RFID involves readers which communicate with tags on a particular frequency and exchange information. In an asset-tracking scenario, each asset would be assigned a unique tag, and each room or compartment of a building would be outfitted with a reader [7] [11] [12] [14] [22]. The benefit of RFID is its explosive popularity in the last decade and the consequent abundance of resources about the technology and a rapid decline in price. The dynamic nature of RFID tracking means that a reader can immediately detect the movement or change in position of a tag, which is immensely helpful in a tracking scenario. The disadvantages of RFID are the extra interfacing that has to be done between the readers and whatever system will be interpreting the tags, as well as the lack of inherent positioning within a building or room. Some systems have been developed to provide localization to within a cubic meter using only RFID technology, but these currently require a large financial investment [11]. Most RFID tracking systems can localize an object only by defining a space within the range of a particular reader, and interpret the presence of the tag within the range as inside that space.

Despite its challenges, RFID offers some concrete advantages that are particularly suited to tracking artifacts inside a museum. Firstly, it is a relatively inexpensive technology. Although RFID tags and readers were very costly at their first appearance, their increasing popularity continues to make prices drop. Secondly, RFID technology can easily be used indoors, as radio signals pass through regular building obstacles.

Although walls and different materials may sometimes decrease the range of a reader or tag, this fact can actually be used to the system's advantage, as rooms and spaces can be more easily defined. Finally, once the desired range of a reader is configured, the localizing of an asset to that range and consequently a particular room is extremely simple; the reader either "sees" the tag or it does not. The asset is then in the room in which the present reader can communicate with the asset's tag. All of these advantages contribute to a system that is well-suited for indoor asset-tracking.

1.2 The Project

The purpose of this project is to produce an automatic asset-tracking system that can provide a more enjoyable experience to a museum visitor, as well as a helpful asset managing tool to museum staff. The project combines the benefits of RFID tracking with an intuitive user interface to accomplish this goal, and it takes advantage of the prevalence of available tracking technologies, along with the widespread ownership of mobile devices, to create a system that is efficient and readily accessible.

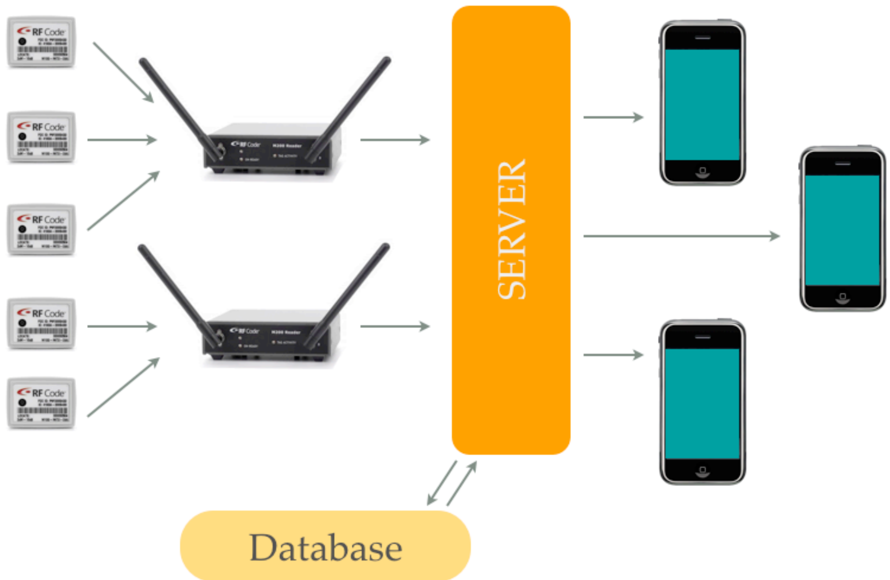

Figure 1. System Diagram

The system can be broken into several main subsystems, as can be seen in Figure 1. RFID tags are assigned one to each artifact, and, in most cases, readers are likewise assigned one to each room. The RFID tags and readers are assembled in an easy-to-use, easy-to-track system. The readers communicate with the tags to determine which tags they can detect and whether any motion has occurred. The readers then pass this information to a server running custom server code that keeps track of assets and links tag identifiers to database entries containing further information about the assets. This same server then communicates with mobile devices to deliver this asset information through an onboard application. This application uses this data to provide dynamic maps and search capabilities to the user. A functional evaluation of the system indicates that it works as desired for tracking assets in a multi-room space and that the mobile application provides an easy, instantaneous way to find assets and access a map of them within the space.

This thesis will describe in detail the design and implementation of the museum artifact-tracking system. It will begin by establishing the need for such a system by looking at previous work in the area. It will then explain the design and functionality of each of the subsystems. A summary of the functional evaluation follows, and the thesis finishes with suggestions for future work as well as conclusions about the entire project.

2.0 Related Work

Since asset-tracking is not a new concept, especially when using RFID technology, there is a large body of related work on the topic. RFID systems are usually implemented in commercial scenarios, where their purpose is simply to keep track of the presence, movement, and location of items. Some of the earliest applications of RFID tagging and tracking were in keycards, toll tags, and public transportation tags [23]. These systems all provided a particular functionality, such as opening a door or paying for a fare, while simultaneously recording where the particular action occurred.

Some work focuses on making RFID tracking available to others. De et al. describe a framework for location tracking using RFID tags [6]. Their work mainly focused on designing and producing a system that could provide tracking functionality in various scenarios, such as in commercial systems or product-recall situations. A system that tracked all the shipments of a product entering or leaving a warehouse could easily help identify all those products that needed to recalled due to a safety hazard or incorrect functionality. Sheng et al. reviewed several existing middleware solutions from academia and industry that provide RFID interfaces to other systems [18].

Many tracking systems using RFID technology have been implemented and studied in various scenarios under different types of strain. Goodrum et al. created an RFID tracking system for use on construction sites to track power tools [7]. Their goal was to make the distribution of tools more equal and more efficient. Their work provides some thorough data about read ranges of RFID tags and readers, especially since their equipment was often used in extreme temperatures and stored in metal containers. Despite the temperature changes and the interference from the containers, the authors showed that RFID tracking was a viable solution, even in an extreme outdoor environment.

A system in Hong Kong used RFID tracking in a shipping container depot to localize available containers that were of the correct type and belonged to the correct company. Ngai et al. recognized the need for automated tracking technology when the necessary containers were often overlooked or accidentally given to the wrong company because of the manual tracking that was being performed [12]. Their system, which entailed both an in-depth Web interface and an SMS interface, helped make the depot more efficient and reduced errors in shipping container storage and use.

Wang et al. turned the concern for the spreading SARS epidemic into a useful, powerful system for tracking patients in a hospital [22]. Their original aim was to keep infected patients from establishing contact with other patients, as well as from superfluous interaction with hospital staff. They designed and implemented a functional system to track not only the movement of hospital patients, but also their temperature. The combined data helped hospital workers deduce whether a patient needed to be quarantined and thus kept the spread of the epidemic low. These authors faced slightly different challenges in needing to track people instead of objects, such as the danger of people voluntarily removing or accidentally losing their tags. They also had to ensure that the radio frequency of the RFID system would not interfere with hospital equipment;

such interference could have cost human lives. Finally, their experience made them realize the importance of building a reliable infrastructure for RFID tracking and not just relying on an application to accomplish tracking goals.

Some systems use RFID technology for applications other than just tracking. Ravindranath et al., the creators of SixthSense, built a tracking system using RFID tags and readers and wrote an accompanying API as a base for additional applications [14]. Although their system does track people and assets via a network of passive RFID tags, SixthSense's contribution is its ability to infer relationships between objects and people simply through their movement and interaction history. The authors use this functionality to provide lost-item alerts, automated room scheduling, annotated videos, and a semi-automated object image catalog for their users. Their system exemplifies the advantages of building an RFID network that can then be utilized for other purposes.

Nemmaluri et al. developed an innovative system named Sherlock that provided accurate localization of objects using only RFID tags and readers [11]. The authors outfitted RFID antennas with pan-tilt-zoom motors in order to scan a space for RFID tags. As it scanned the space, each antenna would keep track of which tags it could see at any given position. If a tag could be seen from two scanning positions, it was interpreted as residing in the intersection of the two reader ranges. Horizontal and vertical scans provided localization in a three-dimensional space. Combining this scanning technique with the presence of several antennas in a space, the authors were able to provide localization to within a meter cubed. Sherlock also entailed a camera and a directory of photographs that it used to show users where a desired object was. Although Sherlock provided acceptable localization, especially for the scale of most museum exhibits, it required the creation of hardware that was not available for purchase, such as the pan-tilt-zoom readers, which made the system both costly and bulky.

Determining the location of objects or people without RFID technology is also a popular area of research. Two projects in particular relate to this thesis because of their goal to provide location- or object-based information to users in an intuitive way. Bruns et al. took advantage of the ubiquitousness of mobile phones to design a system that provided information about museum artifacts [4]. A user would simply take a picture of an artifact of interest with his or her mobile phone, and the application would use image processing to find a close match from a database of images. The authors also used a network of Bluetooth emitters to narrow the scope of the entire museum to a room or two at a time. The authors achieved surprisingly good accuracy (95% accuracy with 155 objects) and the system was a low-cost solution for the museum itself. However, the museum staff had to re-take pictures and re-evaluate Bluetooth emitters every time artifacts needed to move around the museum. Furthermore, the photo-vector data for every artifact in the museum and the Bluetooth-emitter data had to be stored on the phone itself through the application. This storage of information on a user's mobile phone could prove a potential security risk.

The IDeixis system [25] removed this security threat by placing the data with which the application would interact away from the phone. The purpose of IDeixis was to provide a picture-based location search. The authors realized that users are often interested in the things around them and not necessarily their own exact location. The IDeixis system allowed users to take a picture with their mobile phone, send it to a server that searched the Web for image matches, and then returned a number of websites with matching pictures. While the system definitely provided an intuitive location-aware program that essentially let users “point” at an object to find out what it was, the same concerns arose as with the previous project. Images still needed to be stored somewhere, and they needed to be similar enough to provide reliable matches. The authors also encountered the problem of matching images not residing on informative Websites, but possibly on user pages, blogs, or online albums. The lack of control led to a decline in accuracy of returned matches.

The goal of this thesis project is to produce a system that provides reliable tracking, without the worry of burdening the user’s mobile device with application data or the potential for inaccurate results. While this project was already underway, the American Museum of Natural History [1] released an application for iPhones that accomplishes many of the goals set out in this thesis project. AMNH’s Explorer application tracks the user within the museum using GPS and displays the user’s location on a map of the museum. Explorer also gives detailed directions for navigating the museum, displays information about select artifacts in the museum, and guides the user through pre-established or custom tours. However, it is unclear at this time whether the underlying system uses RFID technology for tracking, or whether it makes the same information accessible to museum workers for the purposes of easily maintaining exhibits. In any case, it is a sophisticated application from which much could be learned for future work on this project.

3.0 A Three-Part System

As was mentioned before, this project consists of several main subsystems: the RFID network, the server and web interface, and the mobile device application. Each piece is responsible for a specific portion of the project's functionality, and the success of each piece is crucial to the overall success of the entire system.

3.1 RFID Network

The basic infrastructure of the system is the Radio-Frequency Identification (RFID) network. It provides the backbone of actual asset tracking to the rest of the system. Therefore it is imperative that the RFID network function properly and interface correctly with the rest of the system in order to provide the necessary location information.

Radio-frequency waves are essentially electromagnetic energy waves that provide a basis for communication. In RFID systems, this technology is used between base stations, known as readers, and tags to exchange information. In the most basic case, readers send signals out and wait for a response from tags that have heard and received the signal. These tags then respond back with their own signals, and, if the reader is in range of the tag (that is, it can "hear" the tag's signals), it in turn will receive the tag's signals and know of the existence of the tag within the reader's own range. The range of communication and the information transmitted heavily depends on the type of tag.

Tags are separated into two main categories: passive tags and active tags. The main difference between the two is that passive tags require no on-board battery and therefore draw less power and are consequently cheaper. They draw their power from a reader's communication instead. The electromagnetic waves from a reader are powerful enough to activate the circuit in a passive tag so that it can send its own information back out over its antenna. Although passive tags provide a significant cost and size benefit, as the lack of battery allows these tags to be almost as flat as paper, the tradeoff occurs in the tags' limited communication range. Because passive tags require the energy of a reader in order to communicate, they have to be much closer to the reader in order to receive enough energy to activate; although the range of some of the newest tags extends even to five meters, most passive tags used today have a range of a few inches to three feet [26]. Active tags, on the other hand, are generally more expensive and bulkier, as they require their own battery and often a larger antenna. Their range is much larger, however, and they lend themselves well to tracking projects because of their stronger communication abilities; their signals will not be lost as easily from a further distance or through obstacles.

Different tags, both passive [13] and active [15] can carry different information as well. Some simply carry a unique identifier, which they transmit to a reader to distinguish themselves from other tags. Other tags, however, are equipped with motion sensors, thermometers, and humidity sensors, among other extras, to provide more detailed information depending on the scenario. These tags then transmit this information along with their unique identifiers to the readers around them.

This project uses active RFID tags because of their advantages in asset tracking outlined above. The equipment for this project was provided by RF Code, an RFID-technology and asset-tracking company, so the tags used in this project are M100 active RFID tags [15], which also contain motion sensors for reporting on whether the tag has moved. Although these tags are bulkier than passive tags might be, they are still fairly small at 1.35 by 1.84 by 0.46 inches and could easily be attached to a museum artifact or possibly its accompanying information placard. These tags have a battery life of at least seven years. In this project, each artifact in the museum would be assigned its own tag in order to be uniquely identifiable among all the artifacts.

The readers used for this project were also donated by RF Code. One is the RF Code M220 mobile reader, which is small and portable. It requires frequent recharging of its battery, however, and its mobility is not necessary for a project of this type, in which artifacts move around, but rooms, and consequently readers, stay in one place. The other reader is the RF Code M200 reader, which is a fixed reader that provides continuous communication services. This model is the primary reader used in the evaluation of this project. This reader model is already outdated and therefore does not appear on RF Code's website, but it has similar characteristics to its successor, the RF Code M250 reader [16]. The M250's range in its default configuration is up to 150 feet, but with different antennas could be extended up to 1000 feet. The shorter range would benefit this project, however, as different rooms and compartments would be easier to isolate. At 5.72 by 5.72 by 0.98 inches, the reader is small enough to discreetly install in any room. This project assumed the placement of one reader per every room in a museum, with the exception of oddly-shaped or very large rooms, which could benefit from more than one reader to successfully cover the entire space.

RF Code also provides a powerful framework for integrating with custom applications. Its Code Zone Manager API is a full-service middleware that provides all of the basic asset-tracking functionality. Once the Code Zone Manager software is installed on a Windows or Linux machine, it provides an interface to all of the readers accessible through the machine's network. The reader functionality and information can be accessed through an HTTP or Telnet interface, although all of the commands across all operating systems and interfaces are the same. The HTTP interface lends itself better to integration with custom code, as the HTTP access can be easily programmed into most languages. Each of the two interfaces returns results in one of three standard outputs, as specified by the user: simple text output, Extensible Markup Language (XML) output, or JavaScript Object Notation (JSON) output. The API also provides an easy-to-use GUI via any web browser that allows for simple navigation of the reader-and-tag system. Although this project uses the HTTP interface for its easy integration into server code and the simple text output due to its straightforwardness, the provided GUI was invaluable during project set-up to ensure correct configuration of readers and tags and to gain an intuition into the type and format of information that could be garnered from the readers and tags.

As a full-service middleware, the Code Zone Manager API provides a rich set of commands for managing and receiving information about readers and tags. The commands range from setup commands for adding readers or tags to the system, specifying reader attributes, and activating or deactivating readers, to informational commands such as listing readers or tags and listing reader or tag statuses, to asset-tracking commands such as listing tags visible by a particular reader, listings tags in a certain location, or listing the details for a specific tag. All of these commands are extremely useful in an asset-tracking scenario.

Locations in the Code Zone Manager system are defined as simple objects essentially consisting of only a location name. Locations are then assigned to readers through different read ranges. The different read ranges are interpreted as the strengths of signals being received by the reader; that is, a certain dB range denoting a very strong signal might be assigned to the room that the reader is in, while a range denoting much weaker signals might be assigned to rooms outside the reader room. The reader is then programmed to interpret any signals received at a particular strength as coming from a particular location. These signal-strength location rules can observe channels from any number of readers, so a space in which all the readers can observe a particular tag may be another location altogether.

The basic set-up of the readers and tags involved placing a reader in every room and assigning one tag to each artifact or asset. The readers were configured through the Code Zone Manager GUI to recognize the particular tag group assigned at the factory to the M100 LOCATE tags being used for this project. Locations were then created and assigned to the readers depending on the evaluation location; because the locations are simply measures of signal strength, the transportation of the entire system from one place to another requires the re-specification of location interpretations as all buildings and rooms are different. The read ranges for the locations were generally found using a trial-and-error process, as the number of locations was small and the trial of different read ranges allowed for the discovery of the perfect configuration for the specific situation in any room. The specification of locations and read ranges was also done through the Code Zone Manager GUI.

Once the system was configured, the evaluation of its functionality was simple through the Code Zone Manager GUI. Tag movement and change in location were immediately tracked and noted in the GUI, and the instantaneous feedback helped ensure that the system was set up correctly.

3.2 Server

The second subsystem is the server, which is literally the crux of the entire project, as it provides the interface between the RFID infrastructure and the user's mobile-device application. The server's functionality is the same as for any basic server; that is, to store a certain collection of Web code to provide access to information through an HTTP interface. This project's server also adds database capabilities in order to store further asset-related information.

The server for this project was set up on a Toshiba tablet laptop with an Intel Core Two Duo 2.4 GHz processor and 2 gigabytes of RAM, running the Windows XP operating system. The laptop was outfitted with Apache 2.2 server software [2], PHP functionality, and a MySQL database [9].

PHP is a server-side scripting language that provides dynamic handling of loading conditions inside of a Hypertext Markup Language (HTML) document. It allows portions of the Webpage to load differently depending on the input or conditions at loading time. The use of PHP in this project allows for tag and location information to be loaded dynamically for whatever object is requested.

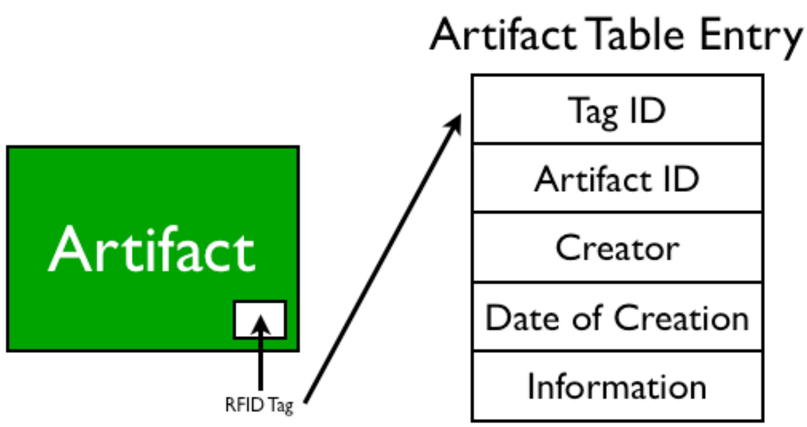

Figure 2. Artifact Table

The MySQL database on the server stores all of the relevant information about every artifact. Because the RFID tags in this project only communicate their own unique identification number, the project required a place to store all of the rest of the information pertaining to the artifacts. Although there could be several tables (collections of data) in the database, including exhibits, artists, and locations, the most important table for this project is the artifact table (see Figure 2). For every artifact in the museum with an assigned tag, there is a corresponding data entry in the artifact table that includes the tag's unique identification number, an artifact identification number, the artifact's creator, the date of creation, and any other relevant background information about the artifact. The separate artifact identification number is sent out to the mobile-device application so it can be used as a reference to the artifact and thus keep the tag's unique identification number secure. Once the mobile device makes a request for a particular artifact's information, the artifact identification number is matched in the artifact table to the correct tag identification number, and the RFID network reports on the tag using only the tag's identification number (see Figure 3).

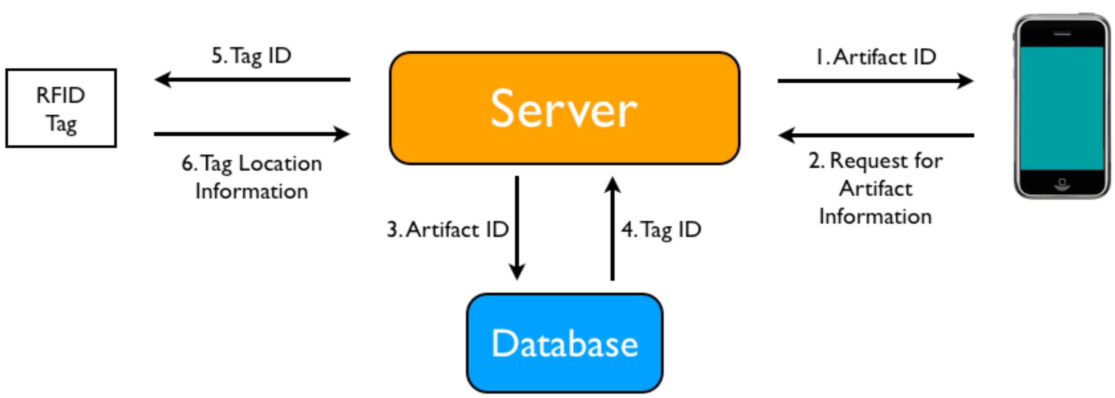

Figure 3. Tag and Artifact IDs

The last function of the server is to provide an interface for the mobile-device application to the database and RFID network data. The server acts as an intermediary between the mobile devices and the RFID network for three important reasons. First, separating the data from the device itself greatly frees up the hard drive space on the device. It would be difficult to store all of the necessary background information for every artifact in a large museum on a mobile device. Often this information includes a photo along with text information, and the storage of such data for hundreds or even thousands of artifacts would strain most mobile devices. Second, keeping the data on the server allows for easy updates. Instead of expecting users to update their application every time they come to a museum to ensure up-to-date information, museum staff can update the information in one place, on the server, and each user can pull down what they need as is necessary. Finally, putting the data on a remote server also helps with security. Because the mobile device does not access the database directly, but rather through a piece of PHP code found on the server, it is more difficult to tamper with the data.

There is a constant exchange of information between the RFID network, the server, and the mobile device. For the most part, if there is no request from a mobile device, the rest of the system stays quiet and no communication is made between the subsystems. Due to the nature of the RFID network, the readers and tags are communicating with each other at a constant rate, but none of this information is passed back to the server until it is requested. Once a user opens and begins using the mobile-device application, however, a flurry of activity is initiated. Because none of the data is kept on the mobile device, aside from the application itself, the device must immediately contact the server for a collection of artifacts or other relevant information. The server directly retrieves this data from the database and returns it to the mobile device. If the application requires the background information for a specific artifact, this information is again requested from the server, retrieved from the database, and returned to the mobile device. If at any point the application requires the location information for a particular artifact or set of artifacts, it again makes the request to the server. At this point, however, the server needs to ask the RFID network for up-to-date location information. Once this data is retrieved from the RFID network, the server interprets the data into a format that will be understood by the mobile-device application and finally returns it to the device. So although not all subsystems are utilized for every event in the system, all of them are crucial to the system's correct functionality.

3.3 Mobile-Device Application

The final subsystem in this project is the mobile-device application. This subsystem is the only one with which the end user will interact directly, so it is important that it be easy-to-use, encompass all necessary functionality, and work correctly. Additionally, the benefit of providing museum information through a mobile application that interfaces with a server would be the user's ability to access all of the same artifact details from anywhere, not just from within the museum. Because of this blindness to the user's location, the user could use the application both inside the museum to download details about a particular artifact and at home to plan a museum visit. If such an application were designed and built well, the museum would have a new outlet for reaching out to and retaining visitors.

3.3.1 Apple iOS Platform

Although applications can currently be written on many different mobile devices, such as Android phones, Windows Mobile OS devices, and Apple's iOS devices, only one platform was chosen for the sake of simplicity. The museum application for this project was built on top of the Apple iOS platform. There were several reasons for this choice. The popularity of Apple, Inc.'s mobile devices has grown tremendously in the past several years. Originally dating back to its first mobile MP3 player, the iPod, Apple's success has grown to include their mobile phone, the iPhone, and their newest mobile device, the iPad tablet. Building off of that success and the prevalence of these devices in today's consumer base allows this project to be immediately accessible to a large group of people. The Apple iOS platform also comes with an extensive amount of online documentation geared toward helping developers learn and understand the operating system. The documentation not only explains the development language that the iOS uses, Objective-C, but it also provides tutorials, API documents, and examples for all of the various built-in frameworks and functions that the iOS provides. This rich set of built-in functionality allows developers to create applications that meet the high standards set by previous iOS-application designers. Apple's Human Interface Guidelines also provide a standard to which all iOS applications should adhere in order to produce the look and feel expected by Apple mobile device users. Once all of the benefits and resources provided by Apple were taken into consideration, the iOS platform emerged as the best choice for this museum application project.

This application was written entirely in the Objective-C and C programming languages using Apple’s XCode development environment and Software Development Kit (SDK) version 4.0. Because the iOS platform extends to all of Apple’s mobile devices, the application was built for both iPhones and iPads (iPod Touches function the same as iPhones for the purpose of this application). Although the application for both devices has the same functionality, the information is presented in different ways to take advantage of the screen size of the iPad and accommodate the limitations of the iPhone. Both versions, however, were built to be simple, intuitive interfaces to the artifacts and exhibits within a museum.

Figure 4. Welcome Screen

The basic features of the application are standard for both versions. Both versions present a “tabbed” application; that is, the various features of the application are accessible through tabs at the bottom of the screen (see Figure 2). Both versions offer search, mapping, and events-viewing functionality. The details of the iPhone version will be discussed first as it was the most important to develop thoroughly, since the market for iPhones and iPod Touches is bigger than that for the iPad.

3.3.2 iPhone Functionality

The first feature of the application is the search function. The ability to dynamically search a museum's offerings is extremely desirable, as it allows visitors to look for a specific artifact, artist, or exhibit. This functionality is also nearly impossible to recreate in printed form, since a museum's offerings could be changing frequently and causing the information to be constantly reprinted. Visually searching through a textual listing of artifacts can also be tiresome and difficult to do, and the desired artifact could be easily missed. Furthermore, searching is a function that follows naturally from asset tracking; if a system already has knowledge of where items are, and, as in this case, has background information on the items, it only makes sense to allow the searching of the same items as well.

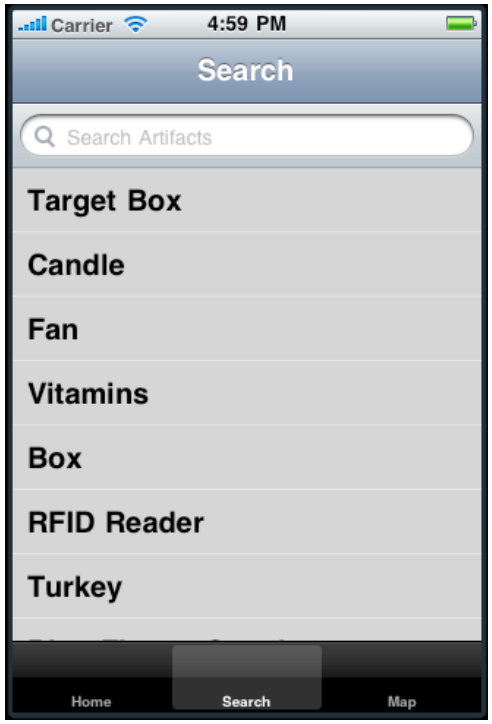

Figure 5. Search Screen

The search function in this application is a straightforward feature that would ideally allow for searching by any search term, e.g., artists, creators, artifact names, dates. Currently the application only allows for searching by artifact name, but this functionality could be easily extended (see Figure 3). When the user navigates to the search tab, a search bar appears and a comprehensive list of artifacts is shown. As a user begins typing in the search field, the results are dynamically filtered to stay relevant. Clicking on an artifact title loads a detail view of the artifact. This detail view shows a thumbnail of the artifact, the artifact name, the author name, the creation date, and the location. Although the result looks fairly straightforward, the loading of the search and detail information requires a round-trip through the server to obtain all of the necessary information.

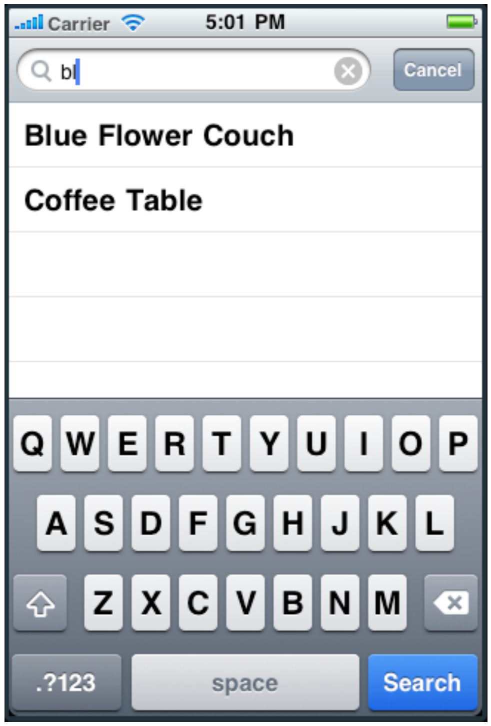

Figure 6. Dynamic filtering of searches.

When the search tab on the iPhone is selected, the application sends a request to the central server to ask for a comprehensive listing of all the artifacts. This initial download of artifacts allows for the application to filter through the listing by itself, instead of having to dynamically request matching results from the server as the user types in the search field (see Figure 4). Although this action could become cumbersome as the number of artifacts gets larger, it also provides a thorough look at what is available at the museum. Additionally, because the listing currently contains only artifact titles and artifact identification numbers, the amount of data being downloaded is fairly small. In the future, the comprehensive listing could be reduced or removed altogether if it proves to be a significant problem.

Once the request for the artifact listing is sent to the server, the server contacts its database to generate the listing. It appends all of the artifact titles and identification numbers together into a simple text string and returns this information back to the application. Once the application receives the data, it parses each artifact into the identification number and its accompanying artifact title. Only the titles are shown to the user; the identification numbers allow the application to know which specific artifact to obtain if the user clicks on its title. As the user types in the search field, the comprehensive listing of artifacts is filtered to display only results that match the user's typing. Because the application dynamically handles this process itself, the user can quickly type and delete typing and still have a near-instantaneous listing of results. At any time, the user can also opt out of searching for a specific title and simply browse through the artifact listing.

Once a user selects a specific artifact, the application once again contacts the server for information. This time the application sends the artifact identification number corresponding to the artifact title to the server along with a request for all of the artifact's background information. When the server receives this request, it searches for that particular artifact in the database using the identification number. The server receives the RFID tag identification number, artifact title, creator, date of creation, and thumbnail from the database, but the location must be obtained from the RFID network. The server uses the tag identification number to request the location of that particular tag from the RFID network. Once the location is returned, the server packages all of the artifact information into a simple text string and returns the string to the application. The application parses the string and presents the artifact information to the user on a new screen (see Figure 5).

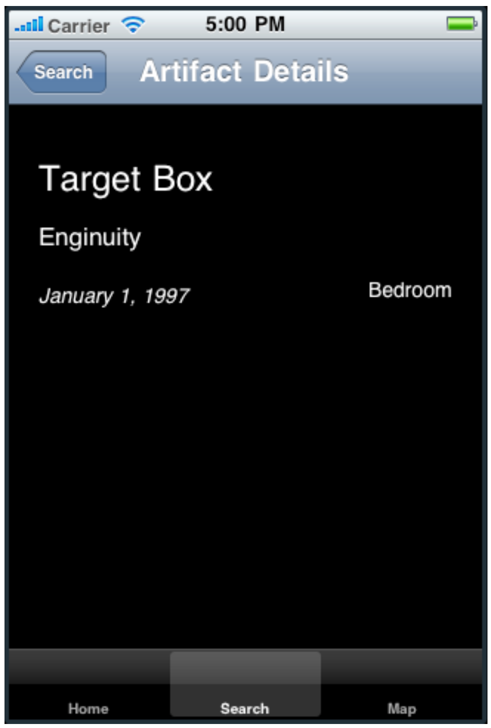

Figure 7. Artifact Detail Screen

The map feature is the second function of the application. As with the search feature, converting the map of a museum to a digital representation greatly simplifies the process of sharing location information with visitors. Maps must be re-printed and redistributed every time artifacts or exhibits move around a museum, and this costly process does not necessarily ensure that visitors receive the information they want. Often maps show only the overall exhibits, not the individual artifacts inside a particular room or area of the museum. Because the underlying RFID infrastructure of this project can be easily set up to identify tags within specific rooms, the mapping functionality of the application can convey the same detailed level of information.

Figure 8. Map Screen

Currently the map feature requires a museum staff member to draw a layout of the museum itself. Because this information will vary from one museum to the next, it must be supplied by someone who knows the layout of the museum well. The layout is specified through a few simple XML commands denoting room name, size, and room floor level (i.e. ground floor, second floor, etc.). Once this layout is created, the application can interpret it as a map, and display it as such to the user (see Figure 6). When the user selects the map tab, a scrollable map of the museum appears on the screen. Each floor of the museum takes up the entire iPhone screen, with additional floors being accessible by scrolling left or right within the map. The rooms on each floor are clearly visible on the map, with their names appearing centered within the room. When a user selects a particular room, another screen pops up from the bottom of the map presenting the listing of artifacts in that room. As with the search feature, if a user selects a particular artifact, a new artifact detail screen loads with further information about the artifact itself.

When the user navigates to the map tab, the application must first contact the server for the appropriate map XML information. The server loads the appropriate file and returns its contents to the application. The XML file is kept on the server and not within the application itself for several reasons. First, removing the file from the application reduces the memory load of the application on the mobile device. Second, if the application were ever adopted by many different museums, it would be much simpler to require each museum to maintain a map XML file on their server than to rebuild the entire application project for each museum. With the XML file on the server, the application can always request the file from the same place on each server and only the leading URL of the server needs to be updated in one line of the entire project. Once the application receives the map XML data, it iterates through the lines of XML, each of which denotes one room, and draws a rectangle of correct size and location on the application map. Once the XML parsing is complete, the entire map of all rooms across all floors is visible. The application also places the room titles from the XML file within each of the rooms.

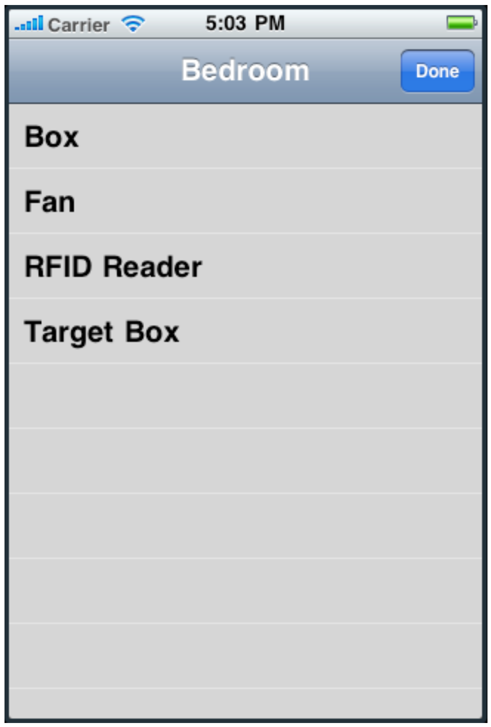

Figure 9. Listing of artifacts in a particular room.

The application does not immediately load all of the artifact data, as not all of the artifacts are visible at the same time so there is no need to retain all of the information at once. Instead, when a user selects a specific room, the application sends a request to the server for a listing of all the artifacts located in that room. Because the server does not own this information, it contacts the RFID network asking for a listing of RFID tags residing in the location specified by the application. The network returns a list of the relevant RFID tag identification numbers, and the server uses these numbers to locate the corresponding entries in the database. Once the entries are located, the server generates a listing of their artifact identification numbers and artifact titles and returns this information to the application. The application presents the artifact titles in a screen that pops up from the bottom of the map and looks very similar to the search screen (see Figure 7). If a user selects a particular artifact from this list, the process for loading the artifact's background information is exactly the same as it is from the search feature.

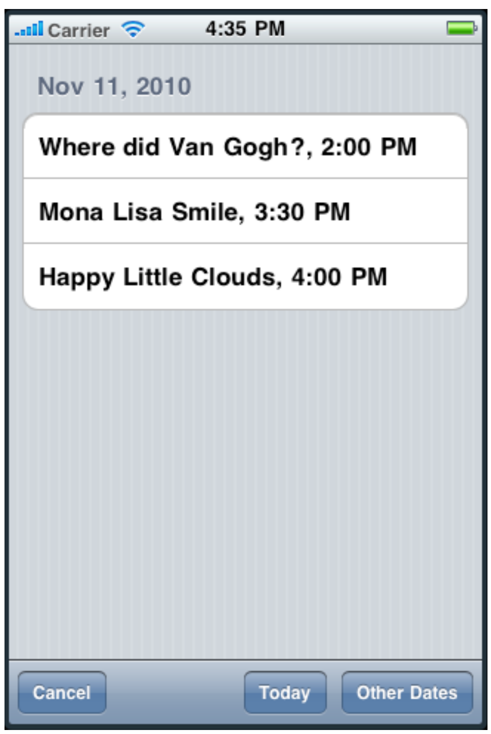

Figure 10. A listing of events.

The final feature common to both versions of the application is that of events viewing (see Figure 8). This feature showcases all of the current events at a museum, both on the day of access to the application and on all other days. As with maps, a museum's event calendar must be reprinted for any change. Because events are likely to change quite often due to additions, cancellations, or even room changes, reprints or corrections could be quite costly. Even if the museum dynamically displays any changes or corrections on a central screen, there is a great possibility that visitors will not notice the change they are interested in. Putting the calendar on a mobile device application allows users to locate the events for a specific day, instead of forcing them to browse through an entire calendar of events. Users can quickly identify events for the day on which they are visiting, as well as for any future visits. Changes to the events are immediately propagated at little or no cost to the museum itself.

When the user enters the application or returns to the home screen, a "Today's Events" button is visible in the center of the screen. When the user selects this button, a new screen pops up from the bottom with the day's date and any events for that day. Each event is listed with its title and time of occurrence. Buttons at the bottom of the screen allow the user to select a different date or return to today's date if a different date is already showing. Selecting the "Other Dates" button brings up a scroll view on which the user can change the month, day, or year, to select a specific date (see Figure 9). The application lists the events for that date when the user returns to the events-viewing screen.

Figure 11. Choosing a different date.

This feature is different from the previous two in that it has little to do with specific artifacts and therefore has no need of the RFID network. The application must still contact the server for events information, however, since the server stores all of that data in order to keep it easily updatable. Whenever the user navigates to the events-viewing screen, either from the home screen or from choosing a different date, the application contacts the server for a listing of events for that particular date. The server searches through the database for events matching the requested date then compiles the list of results and returns it to the application. The application parses this information and displays it accordingly. The user can select different dates an unlimited number of times and can return to the home screen and the rest of the application at any time.

3.3.3 iPad Functionality

Although the iPad encompasses all of these same functions, some of them are displayed differently in order to take advantage of the larger screen real estate. The three sections of the application that currently differ the most from those of the iPhone version are the search feature, the artifact detail screen, and the events-viewing screen. Because the iPad version was developed second and certain iPad features require a near-complete redevelopment of design and background code, not all of these features are as thoroughly developed, although they are designed to work as explained.

Figure 12. Browsing on the iPad.

The biggest difference in the iPad version of the application appears in the search feature. Whereas the search screen in the iPhone application simply presents a list of artifacts and provides a search bar that dynamically filters results, the iPad version provides a "browse" screen in place of the search screen, moving the search bar to the application's toolbar. The browse screen presents the user with many different categories to browse by: artists, time periods, exhibits, artifacts, etc. When selected, each of these categories loads the relevant listing of items and the user can browse through the list and select a specific item to see further information. For example, if the user browses by artists, the application loads a list of artists featured at the museum. Clicking on an artist loads a list of artifacts created by that artist, and clicking on a specific artifact brings up the artifact detail view.

To accommodate this more generic browsing, the application has a pre-set list of browsing categories that it displays in a grid view to the user. Once the user selects a category, the application contacts the server for the appropriate listing of items. The server loads the entire contents of the relevant table in the database - e.g., artifacts, artists, or exhibits - and returns a textual listing of item identification numbers with item titles. The application then parses this information into a table and displays it to the user. If the selection of a particular item requires loading another set of data, as might happen when selecting a specific artist, the entire process repeats again.

Searching for a specific artifact, on the other hand, is included in every screen in the application because of its presence in the application's main toolbar. The search feature functions in precisely the same way as in the iPhone version, but is more accessible because it can be reached from any screen without requiring extra navigation. Additionally, because of the iPad's larger screen, the search window does not take up the entire screen while searching; instead it sits as a floating window on top of whatever information is showing at the time. When not actively searching, the search bar simply sits unobtrusively in the main toolbar.

The artifact detail screen also differs in the iPad version. Whereas the goal in the iPhone version was to present all of the relevant information simultaneously on a small screen, the larger screen of the iPad can provide a more immersive experience for each artifact. Whenever a user's selection leads to an artifact detail screen, the application loads the preview image of the artifact onto the entire screen. The larger artifact image gives users a more-detailed look, allowing them to see the artifact more closely and inspect it further. If the background information such as artifact creator, date of creation, and location are required, a simple tap on the screen brings up a floating window with the requested information. The floating window sits atop the image so both can be seen at the same time. Another tap simply dismisses the artifact information. The process of obtaining all of the artifact information for the detail screen is exactly the same as on the iPhone.

The final difference in the iPad version is a slight adjustment of the events-viewing screen. Because the home screen is otherwise empty, the iPad application immediately shows the day's events on the home screen of the application instead of requiring the click of a button to load another screen. The selected date for viewing can still be updated; otherwise the calendar provides the same functionality as in the iPhone version; it merely takes advantage of the iPad's larger screen to provide a more direct means of disseminating the information.

4.0 Evaluation

The evaluation of this project concentrated on the basic functionality of the system. The goal was to place a set of RFID tags in a space, set up locations with the readers, load the application onto an iOS-enabled device, and test the success of the application itself, as well as the correct location-reporting of all of the tags. This evaluation used one stationary RFID reader, ten RFID tags, and one iPod Touch. The test was set up so that the network of RFID tags spanned three areas. One was named "Bedroom," the second, "Living Room," and the third was purposely set outside the scope of the reader.

The configuration of the locations turned out to be troublesome. Two signal strength rules were assigned to the one reader: one generic rule that simply looked for tags within a certain signal strength, and another that attempted to locate tags with a higher signal strength based off of some reference tag. For this reason, only nine tags actually represented artifacts, while one served as a location reference. The rules were difficult to establish because of the trial-and-error nature of discovering the signal strengths of tags at various points in the space. Many things, such as walls and vertical position, made a significant difference in the reader's communication with the tags. Ultimately, however, the configuration of the rules correctly represented the locations of all the tags in the initial state. The purpose of the one space outside of the reader's scope was to simulate one more area for tags to be in, without having to add the complexity of another rule.

Once the configuration of the reader and tags was complete, the application was loaded onto the iPhone Simulator. A test subject then walked the area, occasionally stopping to look up information about a particular artifact or check the locations of artifacts on the map. The artifacts all loaded in the search tab without any noticeable delay, and artifact detail retrieval occurred on the order of milliseconds as well. The map accurately represented the area and correctly classified artifacts into the correct room, including those outside of the reader range into an “Unknown” room. The information on the application also updated correctly when an artifact was moved from one space to another (The only situation in which an artifact’s location would not automatically update within the application would be in the case that the user never switched screens and therefore the data never re-downloaded. Assuming that the artifacts in a museum are not so frequently mobile and that their movement only occurs when visitors are not present in the museum, this lack of update should not pose a problem. It could be easily fixed, however, by periodic updates on each screen.). From this evaluation, it was clear that the system as a whole was working as expected; the RFID network correctly tracked the artifacts, the server quickly retrieved the information for the mobile application, and the mobile application accurately displayed the results.

4.1 Obstacles

A host of obstacles arose throughout the entire project, but particularly during the evaluation. Although the iOS platform has extensive documentation, it is often difficult to understand the development environment's error messages or, occasionally, lack thereof. The addition of the iPad to Apple's SDK turned out to be more troublesome than expected as well. The author has written applications for just iPhones before without progress-stopping problems, but this experience was different. By the end of the development period, the application ran perfectly on both the iPhone and iPad simulator, as well as on the physical iPad device. The application would not load onto the test iPod Touch, however. Although there was no clear indication on any of XCode's feedback screens as to the reason for this failure, the issue may have been caused by a mismatch in iOS and SDK versions. Hours of debugging and searching for help produced no results. Ultimately, the application had to be largely tested on the iPhone simulator, as the iPad version was still in a raw form. This was a disappointing compromise, although the Simulator provides a fairly accurate representation of true functionality.

A secondary evaluation which deployed the iPhone version onto the iPad confirmed that the application behaved as expected, communicating successfully with the server and accurately displaying artifact information. The portions of the iPad version that were finished also worked correctly, including those functions that communicated with the server and onto the RFID network.

5.0 Future Work

This project has a tremendous amount of potential for future work. The project outlined in this thesis is merely the foundation and infrastructure for growth and expansion, both in scope and in features. There are many areas of the whole system that could be improved, and there is entirely new functionality that could be added to appeal to more users.

Different types of hardware could be added to the infrastructural level to increase the accuracy and usefulness of the system. RF Code already provides infrared (IR) room locators for pairing with an RFID network. These room locators use IR technology to communicate with RF Code's RFID tags, many of which have built-in IR sensors. Each room locator is installed in a specific room, and tags are instructed to tell RF Code's Code Zone Manager if they can "see" a particular room locator. These tags can then be interpreted as being in a particular location much more accurately than when using signal strength and RFID readers alone. Although they would constitute an extra cost, IR room locators would significantly diminish the amount of per-project configuration needed. Instead of having to determine which signal strengths corresponded to which rooms for particular readers, a museum staff member could simply set up a room locator in every space of the museum and denote that locator as belonging to that room. The disadvantages of using IR must be kept in mind when considering this improvement, however. IR has a smaller range than do radio frequency signals, and IR transmitters must have a direct line of sight to any readers. This means that the direct path between a transmitter and a reader must be completely unobstructed or communication will be interrupted. Museum staff members for a particular project would have to be careful to place the tags in a more visible place, which could in some situations disrupt the exhibit. Furthermore, using IR locators would not provide exact localization for the system, only an easier way to locate tags within a particular room.

Bluetooth transmitters within the system's infrastructure would help with localization. Bluetooth wireless technology would be especially well-suited to a project like this as most mobile devices now have Bluetooth capabilities. A Bluetooth transmitter placed on every artifact or group of artifacts could communicate with the application on a mobile device to establish a connection. The application could then look up that transmitter's Bluetooth identification ID with a central server to determine the transmitter's location. At that point, the application could determine that its mobile device must be near to that location due to Bluetooth's relatively short range [24]. Localization opens up another world of resources for this project, as will be discussed shortly. The disadvantages with Bluetooth would be, again, added cost and increased amounts of required configuration. Although this configuration would only have to be done once, as with the RFID readers, now the central server would have to retain identification and location information about all of the Bluetooth transmitters as well. The increased network strain of mobile devices communicating with the server for another feature might also prove a problem for larger museums. The added benefit of localization capabilities, however, could likely outweigh these disadvantages.

An effective way of making the project more useful and more appealing to a wider group of people would be to provide a teacher portal. By using the infrastructure and functionality already in place, a future effort could build a web portal especially meant for teachers. This portal could provide suggested museum tours for specific topics as well as the capability to create new museum tours to accommodate teachers' lesson plans. The accompanying mobile device application could be altered to provide a "check-in" feature that would allow students to confirm that they had seen a particular artifact on their teacher's museum tour. Students could then traverse the museum on their own, or the project could be paired with a collaborative learning activity to provide even more educational value.

The application itself has many places for growth and improvement. First, it could be much more useful to a museum visitor if it was location-aware. Taking advantage of localization services provided by a Bluetooth network or some other kind of technology, the application could display much more detailed information for the visitor. The application could easily tell the user exactly what artifacts or exhibits were in the room with the user. Dynamic maps could display a step-by-step path through the museum for any chosen or created museum tour, and then alert the user if he or she has strayed off the path. Along the same lines, the application could lead the visitor to a particular exhibit or event with a map or step-by-step directions personalized to the user's current location.

Another useful feature would be the ability of users to create their own museum tours for a more personalized experience. While searching or browsing through artifacts, users could mark certain artifacts that the application would save and then produce as a unique museum tour. Ideally the application would also provide the best path through the museum for any specific tour, custom or otherwise. Another functionality that would help with the creation of museum tours would be that of suggesting other artifacts or exhibits. Much like the suggestion features on many e-commerce sites today, the application could aggregate previous visitors' opinions or viewing habits, as well as utilize themes provided by museum staff, to suggest additional artifacts for a visitor to view. These features would be especially helpful in a large museum with too many artifacts to view in one visit or with which visitors are not familiar.

The application should also ideally be ported to additional platforms. Because the project is divided into distinct subsystems, moving the application to another mobile device platform would require only the re-development of the application itself. The RFID network and the central server would remain unchanged. The extension of the application to Android and Windows Phone platforms would allow it to be accessible to millions of more users [5].

The application would also greatly benefit from a usability study. Usability "refers to how well users can learn and use a product to achieve their goals and how satisfied they are with that process" [20]. A museum application such as this one needs to be easy-to-use from the very beginning, so that visitors will immediately take advantage of it and find it helpful. If the application is in any way confusing or unclear, the visitor will most likely abandon it and the entire purpose of the project would be defeated. An ideal usability study for this application would gather a representative group of users from different age groups, with varying levels of familiarity with the museum, and of different museum-viewing habits. These users would then be asked to perform a series of tasks within the application and the efficacy of these tasks, along with the degree of user frustration or satisfaction, would be measured. The feedback from the usability study would be invaluable toward improving the layout and overall feel of the application. Better immediate understanding of the application means more visitors using it, which could lead to return visits or encouraged visits of others.

Finally, the entire system should be deployed in a real museum. Several efforts were made throughout this project to establish contact with various museums and attempt a real deployment, but the project was never released in a museum and tested on a full scale. Although an initial functional evaluation is helpful, the true success and worth of the system will not be known until it is functioning within its correct environment. Therefore, one of the greatest improvements upon the current projects would be its deployment and evaluation in a real museum.

6.0 Conclusions

A museum's goal is to present its artifacts in such a way as to attract and retain visitors. This objective is often hindered by the manual errors of tracking and updating museum artifacts. A system that would automatically keep track of the locations of all artifacts, paired with their background information, could be an asset of great value to a museum. This project aims to provide such a system for museum owners and staff.

By linking together three distinct subsystems, this project establishes a reliable framework for artifact-tracking and display in a museum. The first subsystem, the RFID network, handles the communication of RFID tags and readers to determine which readers can "hear" which tags. Through the aid of the industry solution RF Code Zone Manager and with some initial configuration, the RFID network can communicate the locations of all known tags. Once this information is available, the second subsystem, the server, can store the background information of the artifacts associated with the RFID tags. It also communicates with the RFID network for instantaneous location updates, as well as with the third system, a mobile device application. The application makes requests to the server for both background and location information for artifacts and displays this information to the user. The application presents this information in such a way as to be helpful in navigating the museum and finding artifacts of interest. Together, the three subsystems form a reliable, artifact-tracking museum guide.

Although the system already provides a successful proof of concept, many improvements can be made to make the application more useful and more appealing to a larger group of people. Once some of these additions are in place, the system should be evaluated for its usability and then deployed in a real museum to serve as an aid to both visitors and museum staff.

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VITA

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